R&D ON HEAT PUMPS WITH NATURAL WORKING FLUIDS IN JAPAN

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The conventional refrigerant R22 has been replaced by hydro-fluorocarbons, and the recovery and destruction system for fluorocarbons began operation in Japan. However, for future global warming prevention, it is said that conversion to natural working fluids will be required. In this paper, the overview of the research on the heat pumps using the natural working fluids in Japan is summarized. The carbon dioxide systems for mobile air conditioners and water heaters are actively researched. The heat pump water heaters operated in midnight were put on the market, and the spread is expected. Hydrocarbon heat pumps for air conditioning are not on the market from a viewpoint of safety. Only a small amount of refrigerators operated with isobutene is sold in Japan. Although the ammonia refrigerators are the ripened and reliable technology, the law requires expensive safety facilities, and therefore they are only used for the low-temperature warehouse or for the industrial use.

1. INTRODUCTION

The energy consumption in the commercial and residential sector in Japan occupies 26% of the whole, and the growth is as large as the transportation sector. Figure 1 shows the transition of final energy consumption of each sector, in which final energy consumption in 1990 is set to 100. According to these consumption statistics, both the household use and the business use in the commercial and residential sector show growth higher than a whole average. About 40% of the cause of the growth of the household use is the increase in the number of households, about 30% is the increase in the power consumption of electric products, and about 30% is increase of the energy consumption for air conditioning. About 80% of the cause of the growth of the business use is increase of the floor area of business-use buildings, and the remainder is increase of the power consumption by the increase in information machineries and equipment. Since about 30% of energy consumption of the business use is used for air conditionings, the increase

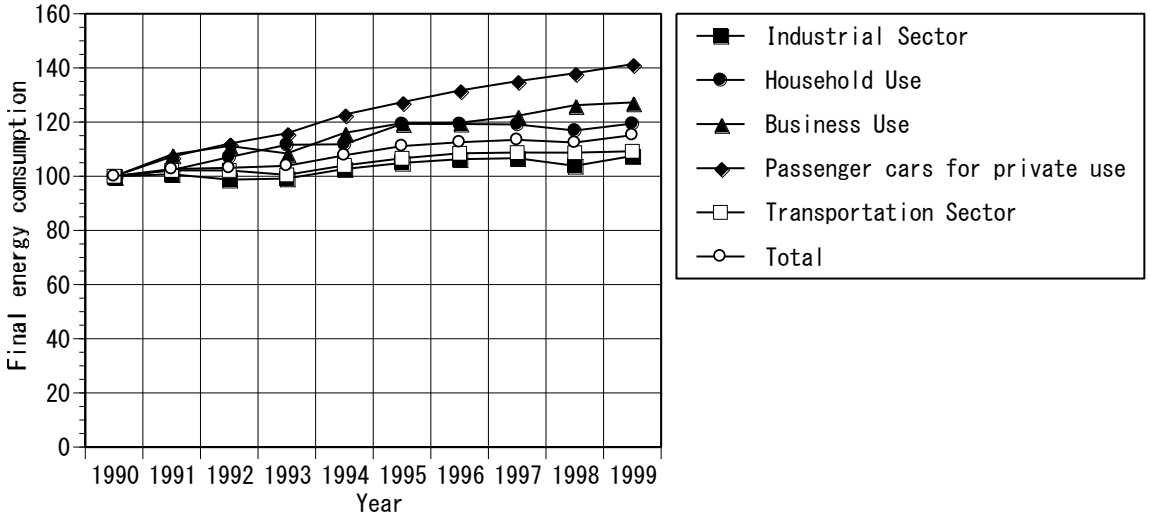

Fig.1 Changes in final energy consumption by demanding sector in Japan

of floor area results in the increasing energy consumption. Since we pursue a continued comfortable life, the energy consumption is continuously growing, and huge amount of energy is spent on the air conditioning.

For global warming prevention, the Law Concerning Rational Use of Energy calls for energy conservation of home electronics in Japan. The energy-conservation standards of the air conditioners for both heating and cooling purposes by the revised Law Concerning Rational Use of Energy enforced in 1999 are shown in Table 1 (ECCJ 1999). The air temperature conditions in the performance test are the standard cooling conditions and the standard heating conditions specified in the Japanese Industrial Standard B8616 or C9612, as shown in Table 2. The arithmetic average of the COPs by the both tests is asked to exceed the values in Table 1. The COP target values of business-use air-conditioners are fairly lower than those of residential air-conditioners. When this energy-conservation standard was established, the business-use air-conditioners had the low concern about energy saving compared with the home air-conditioners, and the inverter was not introduced. The business-use air-conditioners with which average COP exceeds 4 are put on the market now, and the consumer's concern about energy conservation is increasing.

Table 1 Standard energy consumption efficiency.

Type of air conditioner	Cooling capacity				
	2.5 kilowatts or less	More than 2.5 kilowatts but 3.2 kilowatts or less	More than 3.2 kilowatts but 4.0 kilowatts or less	More than 4.0 kilowatts but 7.1 kilowatts or less	More than 7.1 kilowatts
Non-ducted and window-mounted type	2.85				
Non-ducted and wall-mounted type	5.27	4.90	3.65	3.17	3.10
Non-ducted types other than the above	3.96	3.96	3.20	3.12	3.06
Ducted type air conditioners	3.02			3.02	3.02
Multi-type air conditioners that separately control the operation of indoor units	4.12			3.23	3.07

Table 2 Standard air temperature conditions specified in JIS C9612 and B8616.

Test	Indoor air		Outdoor air	
	Dry bulb temperature	Wet bulb temperature	Dry bulb temperature	Wet bulb temperature
Standard cooling test	27°C	19°C	35°C	24°C
Standard heating test	20°C	-	7°C	6°C

For another measure of global warming prevention, a duty of the refrigerant recovery at the time of air-conditioner abandonment was imposed in Japan. As for the refrigerant used for the business-use air-conditioners and the automobile air-conditioners, a duty of recovery and destruction was imposed by the fluorocarbon recovery and destroying law from 2002. As for the refrigerant used for the residential air-conditioners, the similar duty was imposed by the law requiring the recycling of home appliances from 2001. Although the air-conditioner

manufacturers are making the system for collecting fluorocarbons and not revealing to the atmosphere, it is not easy for them to recover completely. Since the possibilities of HFC refrigerants are indefinite, the concern about natural working fluids is increasing.

Although the conventional refrigerant R22 has been replaced by the HFC refrigerant, the expectation for natural working fluids is growing especially in European countries. When the refrigerant recovery at the time of abandonment does not progress in Japan, introduction of natural working fluids may have to be considered. An advantage of natural working fluids is their low GWP. However, if the COP of the heat pump using a natural working fluid is remarkably inferior compared with the conventional refrigerants, such as R22, the carbon dioxide emissions accompanying the power consumption under operation will increase. It is necessary to secure the reservation of safety and the high COP in using a natural working fluid. In this paper, the outline of the natural working fluids research in Japan is introduced. Table 3 summarizes the current status of each natural working fluid.

Table 3 Summary of natural working fluids

	Advantages	Faults	Application
Carbon dioxide	•Neither toxic nor flammable •Negligible pressure drop •Suitable for temp. booster	•Low COP •High pressure (10MPa)	•Water heater •Mobile A/C •Cold district heating
Propane Isobutene	•Mineral oil can be used. •COP is similar to R22.	•Flammable •International standards are required.	•Refrigerator •Vending machine
Ammonia	•COP is higher than R22. •High heat transmission •High latent heat	•Toxic and flammable •Copper material cannot be used. •Safety facility is expensive.	•Commercial refrigerator •Chillers for industrial use
Water	•Neither toxic nor flammable •High COP •Vacuum operation	•Large compressor •High pressure ratio •High initial cost	•Chiller for industrial use •Ice-maker
Air	•Neither toxic nor flammable	•Low COP in A/C use	•Low-temperature warehouse

2. CARBON DIOXIDE

Since carbon dioxide does not have toxicity or inflammability, it has been developed as a working fluid for automobile air-conditioners. The major manufacturer of automobile air-conditioners Denso Corporation and Mitsubishi Heavy Industries independently developed scroll type compressors. Since a difference between high-pressure and low-pressure of carbon dioxide cycle is large, loss by leak is large and big thrust load acts on a thrust bearing. Mitsubishi Heavy Industries developed a new bearing in which the thrust load is reduced by adding high-pressure oil from the back. The compressor efficiency is shown in Fig. 2 (Hirao et al. 2000).

The research on the heat pump water heater operated with carbon dioxide progressed, and three manufacturers had put residential systems on the market in 2002. Figure 3 shows an advantage of CO_2 for heat pump water heaters using a temperature-entropy chart. The critical temperature of CO_2 is 31.1°C, and thus the cooling process is in the supercritical state. The cooling device is called a gas cooler instead of a condenser, because no phase change occurs in the gas cooler. The fluid temperature in the gas cooler becomes low even if the pressure is kept

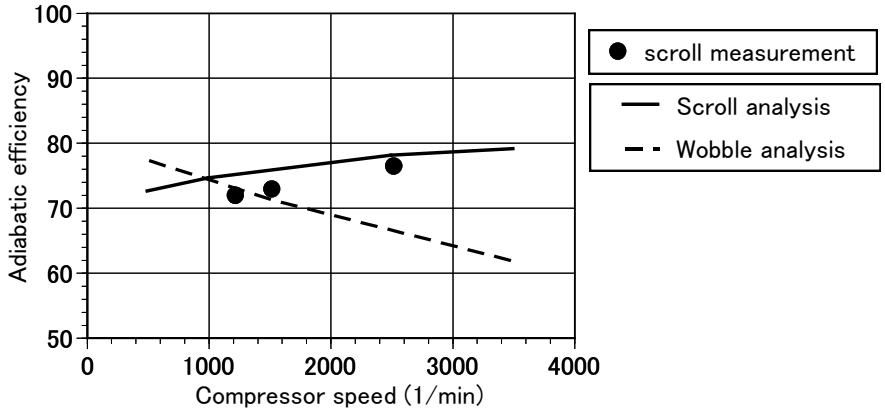

Fig.2 Efficiency of prototype CO_2 scroll compressor by Mitsubishi Heavy Industries.

constant. Therefore, by using a countercurrent gas cooler, irreversible loss in the gas cooler can be reduced. Average COP of the products is 3.0.

These heat pump water heaters have less energy consumption and less carbon dioxide emissions than a conventional gas combustion water heater. The heat pump water heater makes hot water using cheap midnight electric power, stores hot water in a tank, and hot water is used in the daytime. In order to proliferate and to promote high-efficiency hot water systems, the government assists a part of installation expense of this system, and therefore it is very economical. Table 4 shows the summary of the developed CO_2 compressors. Figure 4 shows the performance of Denso's compressor, where the COP for heating is the ratio of heat rejection at the gas cooler to the compression work (Saikawa et al. 2000). Figure 5 shows the comparison between single-stage compression and two-stage compression by Sanyo Electric (Sato et al. 2002). The COPs are normalized by the value at 80Hz of compressor speed for single-stage compression. For two-stage compression the compression ratio at each stage is so small that the leakage from the compression parts is also small. Resultantly the COP of two-stage compression is higher than that of single-stage compression especially in low compressor speed region. Table 5 summarizes the specification of the Daikin Industries heat

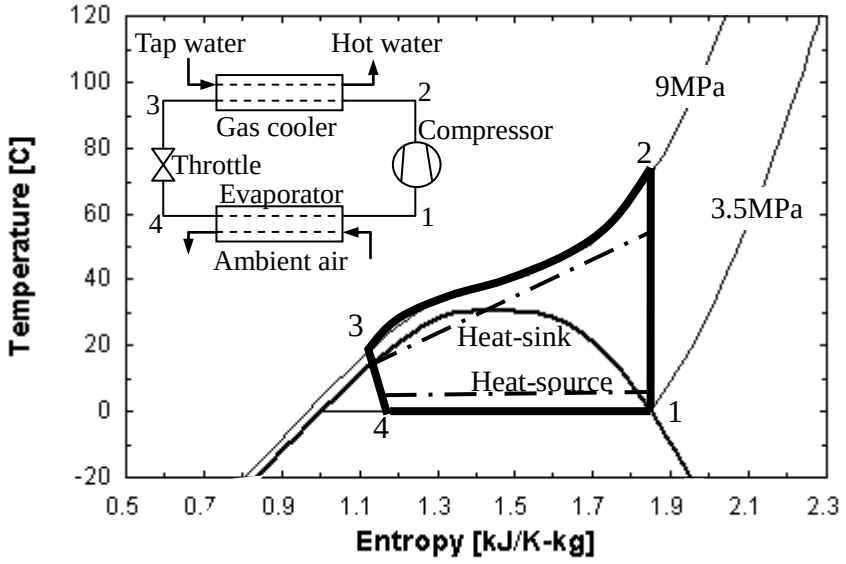

Fig.3 An advantage of CO_2 for heat pump water heater.

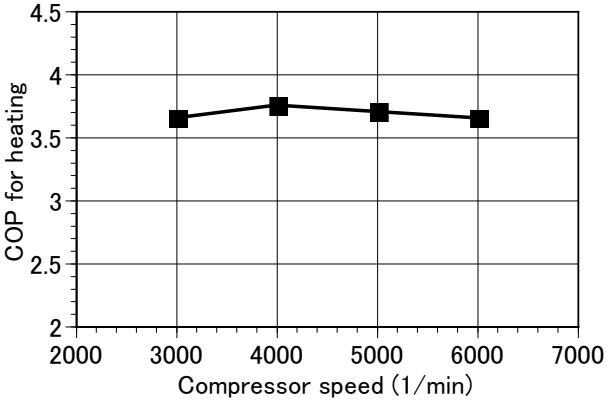

Fig. 4 Efficiency of CO_2 compressor by Denso Corporation. Suction and discharge pressures are 9.8 and 3.9MPa, respectively. Superheating is 10°C.

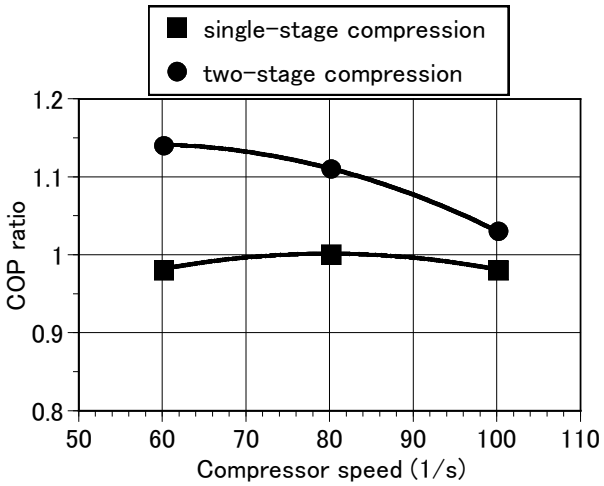

Fig. 5 Efficiency of CO_2 compressor by Sanyo Electric. Suction and discharge pressures are 9 and 3MPa, respectively. Suction gas temperature is 35°C.

pump water heater (Daikin 2002).

Table 4 Specifications of CO_2 compressors for water heater.

Manufacturer	Denso Corporation	Sanyo Electric	Daikin Industries
Type of compressor	Scroll type	Two-stage rolling piston type	Single-stage swing type
Motor type	DC motor-inverter	DC motor-inverter	DC motor-inverter
Size	¢137 x 285	¢118 x 217	¢126 x 265
Swept volume (cm^3)	3.3	2.89	3.4

Table 5 Specifications of Daikin Industries heat pump water heater

Rated heating capacity	4.5kW
Power consumption	1.21kW
COP at standard condition (*)	3.72
Sound in operation	45dB
Water tank capacity	370L or 300L
Hot-water temperature in tank	65 ~ 90°C
Hot-water supply temperature	36 ~ 48°C
Range of ambient temperature	-10 ~ 43°C

(*)Ambient temperature: 16°CDB/12°CWB, tap water temperature: 17°C, hot water temperature: 65°C

Fig. 6 Daikin Industries heat pump water heater

3. HYDROCARBONS

It is very hard to use hydrocarbons as a working fluid for air-conditioners due to its inflammability. Although isobutene operated refrigerators are widely used in Northern Europe and Germany, they were not sold in Japan until last year. Of course, some Japanese

manufactures were exporting the HC compressors to Europe. Last year the Japan Electrical Manufacturers' Association (JEMA) decided upon an independent standard for HC refrigerators in Japan. This standard was not attested by the governmental institute, but the guideline for the production of HC refrigerators was given. Taking the feature of Japanese refrigerators and living situation into account, JEMA proposed the standard, which was a little different from the IEC standard for flammable refrigerant (IEC335-2-24).

(1) The object of this standard is limited to the refrigerator below 800 liters of the rated internal volume.
(2) The amounts of filling refrigerant for forced convection type refrigerators must be less than 100g, while that for natural convection type refrigerators must be less than 150g. The forced convection type refrigerators, in which cold air is circulated by a fan, are in use in Japan.
(3) The restriction of the electric heater for defrosters is added.
(4) The cooling piping in a warehouse must be dual structure. Electrical appliances must have explosion-proof construction.

From the beginning of 2002 Matsushita Electric Industrial and Toshiba started to sell HC refrigerators in Japan. HC refrigerators will gain a certain amount of market share in the near future.

Introduction of ice thermal storage equipment is progressing for electric power load equalization in Japan. Zeneral Heatpump Industry and Chubu Electric Power jointly developed a heat pump chiller, which used propane as a working fluid in 1999 (Shiba and Atsumi 2002). This machine has the following functions; generation of the hot water and cold water for air-conditioning, generation of the ice which uses cheap electric power at midnight, and the hot-water supply. By performing simultaneously ice thermal storage operation and hot-water supply operation, it is designed in the summer to perform the efficient exhaust heat recovery operation. In order to minimize the leakage of the refrigerant to the air at the accident, the refrigerant system is divided into several suitable units. The specification of the minimum unit is summarized in Table 6.

Table 6 Specifications of the minimum unit of ice thermal storage heat pump chiller.

Cooling capacity	17.3kW	Refrigerant	Propane
Ice storage capacity	13.4kW	Filling refrigerant	5kg
Heating capacity	19.7kW	Size of chiller	1.7x0.8x1.8m
Hot water capacity	17.3kW	Size of ice storage tank	2.0x2.5x1.5m
Type of compressor	Semi-hermetic reciprocating	Output power of compressor	5.5kW

4. AMMONIA

Since utilization of ammonia is the ripened technology, there is no serious technical problem for spread. The efficiency of refrigeration equipment using a secondary coolant is equal to or higher than fluorocarbon equipments. But safety facilities are required and make it high cost due to its inflammability and toxicity. The followings are the research items for further spread.

(1) Curtailment of the amount of filled refrigerant

By using soluble lubricant PAG, small tube piping, and heat transfer enhancement, the size of heat exchangers can be made small. Brazed plate heat exchangers are used abundantly.

(2) Curtailment of the leakage

Development of hermetic compressors is one of the most important technologies to prevent ammonia from revealing. Since copper cannot coexist with ammonia, in order to make a hermetic compressor, a canned motor has been used. But the efficiency of canned motor is low. Currently a canless motor, in which aluminum wire is used, is developed.

Maekawa Mfg. is a leading company of production of compressors for ammonia in the world. Maekawa Mfg. newly developed a high-efficiency semi-hermetic canless screw compressor for ammonia refrigerant (Maekawa 2000). Aluminum is used for wire in motor, and Teflon is used as material for insulator. It is reported that the efficiency of canless motor is 92%, which is similar to an open type motor, and is higher than a canned motor by about 7%. Figure 8 compares the performance of ammonia refrigerator with that of R22. The vertical axis is the ratio of the COP of ammonia refrigerator to that of R22. In high and medium temperature region the COP of ammonia system is higher than that of R22 by about 10%.

Fig. 7 Semi-hermetic canless screw compressor for ammonia by Maekawa Mfg.

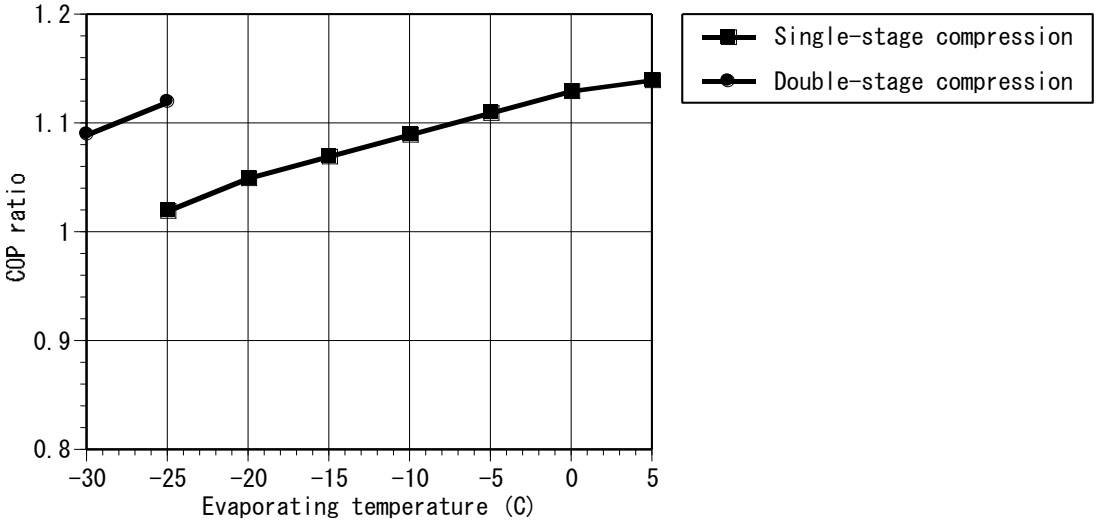

Fig. 8 Comparison of the refrigerator performance between ammonia and R22.

5. CONCLUSION

An overview of research and development of heat pumps for natural working fluids in Japan is given. There are many compressor suppliers in Japan. Development of compressors for natural working fluids is actively undertaken. In the future, when the use of HFC refrigerant will be regulated, the role of Japanese companies will become more important.

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